

Wavelength selection for multilayer coatings for the next generation EUV lithography

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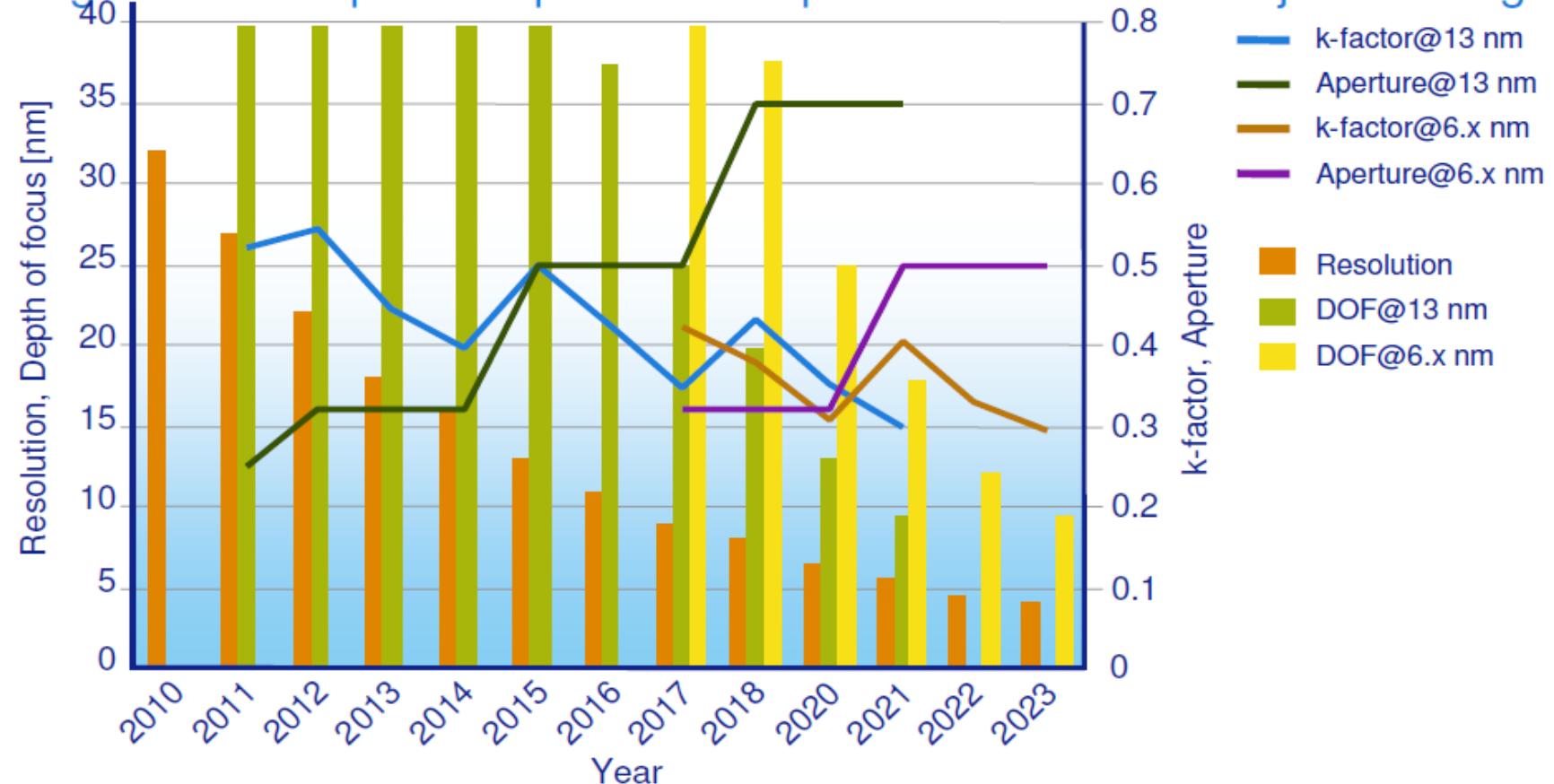
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Opportunity to extend of EUV down to sub 5 nm possible

increasing apertures up to 0.7, wavelength reduction down to 6.8 nm using 13 nm compatible optics with depth of focus as the major challenge



ASML presentation: 2010 International
Workshop on EUV Sources, Dublin, Ireland





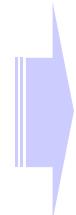
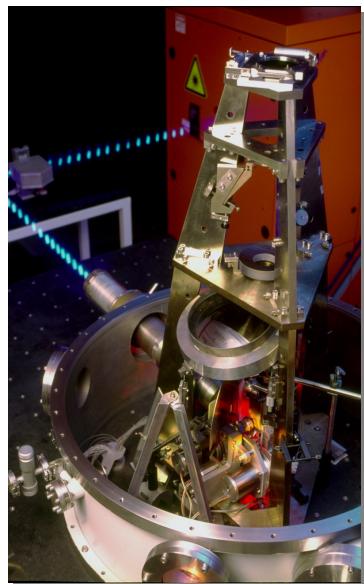
Outline

- FOM, who we are ...
 - 13.5 nm research
 - Need for shorter wavelengths optics
- 6.x nm multilayer issues relevant for performance and choice of optimum operational wavelength
 - Passivation of La with Nitrogen
 - Roughness reduction
 - $B_4C \rightarrow B$
- Wavelength selection: multilayer reflectivity profile @ 6.5-6.9 nm



EUVL: from basic research → development labs

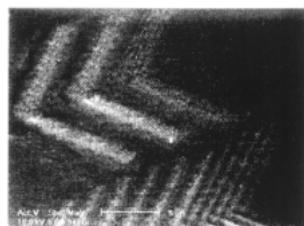
FOM pilot research on lithographic imaging using 13.5 nm (1992)



Two prototype 13.5 nm wafer scanners: ASML Alpha Demo Tools, ADT, including Zeiss and FOM ML-optics

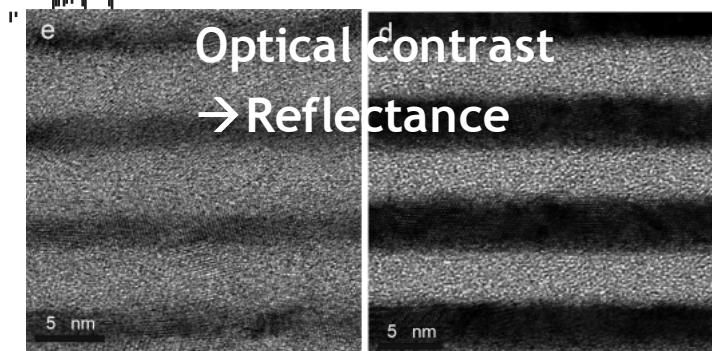


13.5 nm exposures in resist



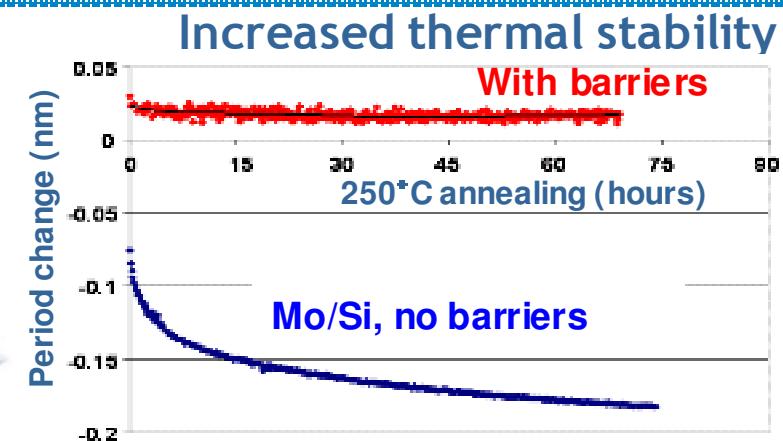
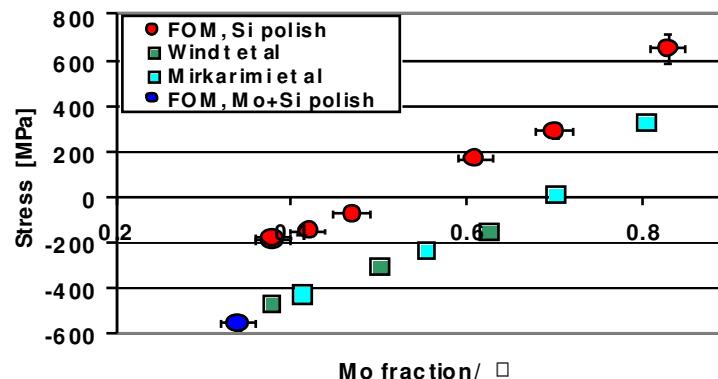
λ	13.5 nm
NA	0.2
# Multilayer optics	10
Max diameter	45 cm
Resolution	~ diffraction limited

14 year of research on Mo/Si optics!



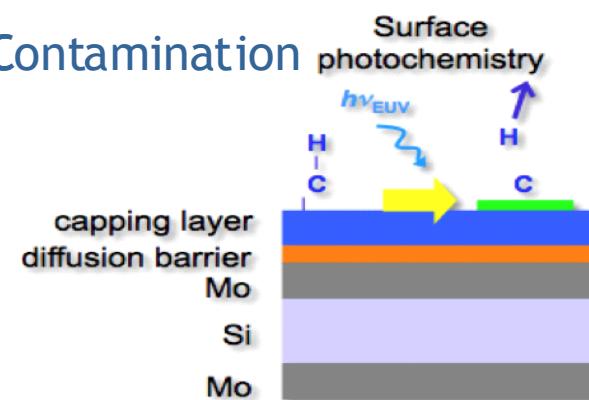
Coating uniformity
Periodicity control

Stress reduction



Bandwidth

Contamination



E. Louis et. al., Prog. Surf. Sci., doi:10.1016/j.progsurf.2011.08.001, 2011



Downscaling λ to next generation EUV: 6.x nm

$\lambda = 13.5 \rightarrow 6.X \text{ nm}$

Novel ML coatings:

- New materials: Mo \rightarrow La, Si \rightarrow B (B_4C)
- Reduced bi-layer thickness: 6.8 \rightarrow 3.4 nm
- Requirements interlayer quality scale with λ

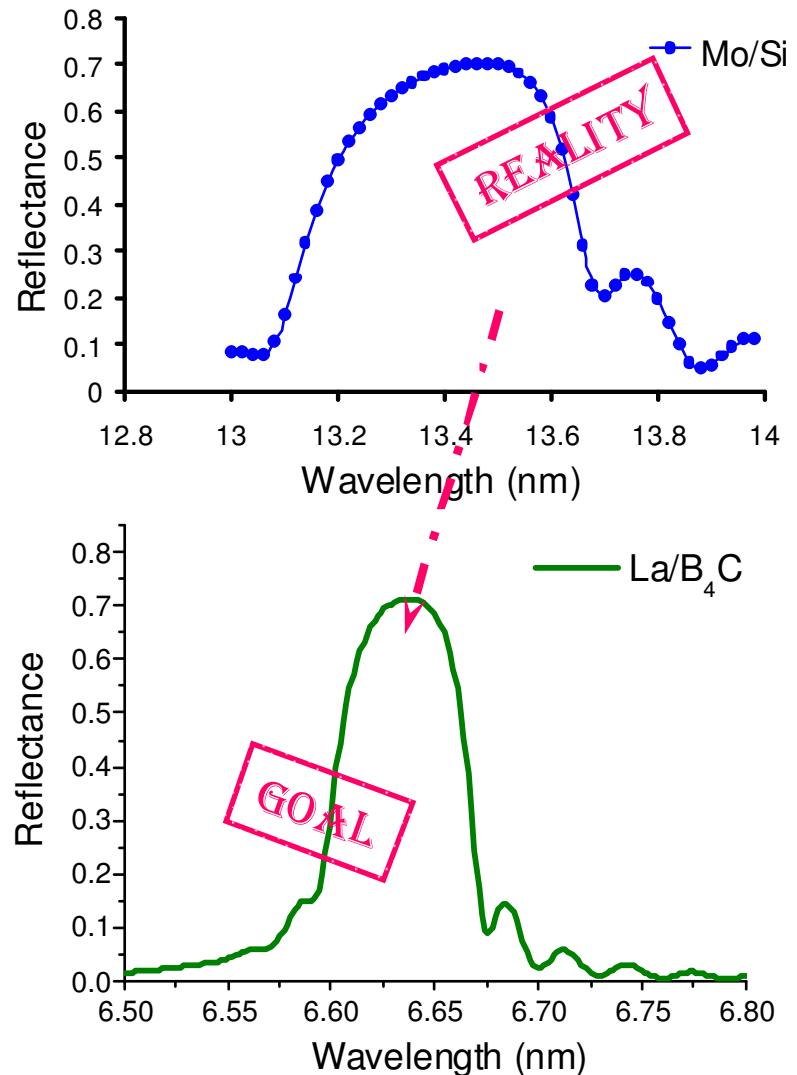
Baseline technology required:

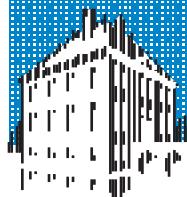
- Reduction of layers intermixing
- Roughness mitigation
- Optimization of optical contrast
- Search for optimal ML performance

Technological aspects:

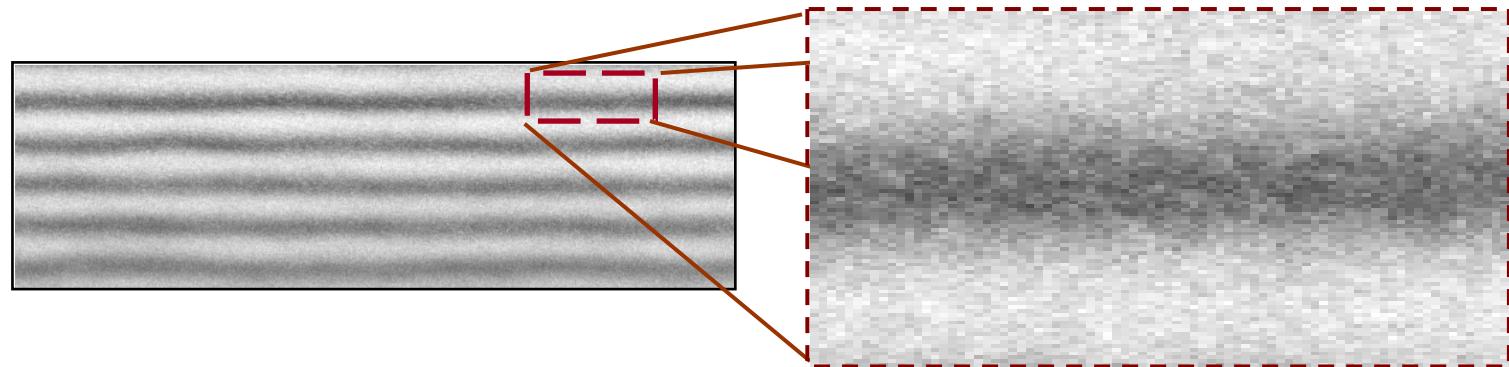
Additionally to coating issues

- More bi-layers: @13.5 nm N=50 @6.x nm N~200
- Bandwidth of the optical column $\Delta\Sigma/\lambda(Mo/Si)=2\%$
- $\Delta\Sigma/\lambda(La/B)=0.6\%$





1st challenge: thermodynamics @ La/B₄C interfaces



The first TEM image → blurred interfaces are observed: **La-B compound formation?**

Compound	La	B ₄ C	LaC ₂	LaB ₆	LaN
ΔH ^{for} (kJ/mol)	0	-71	-89	-130	-303

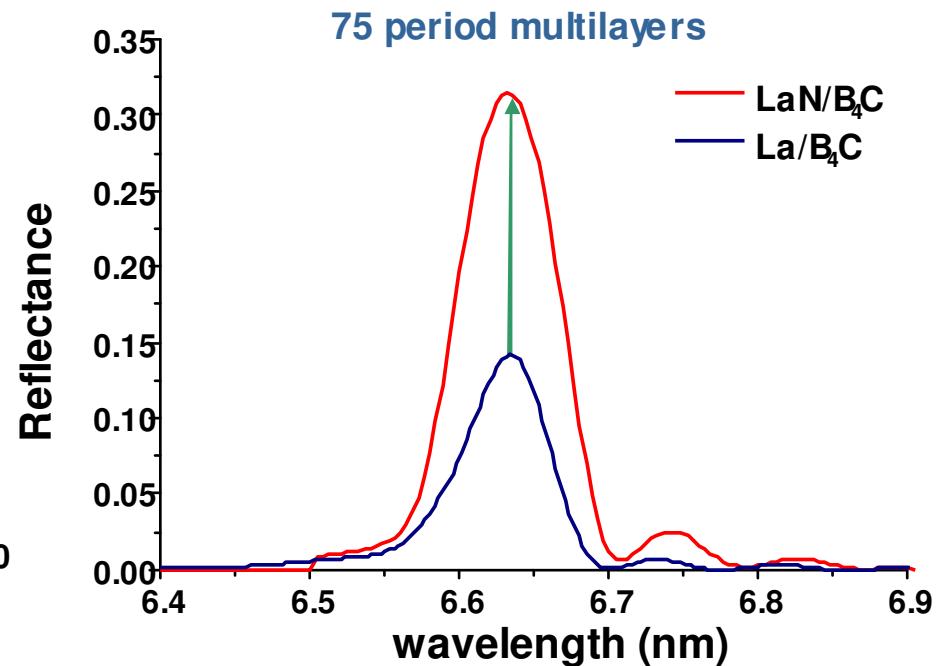
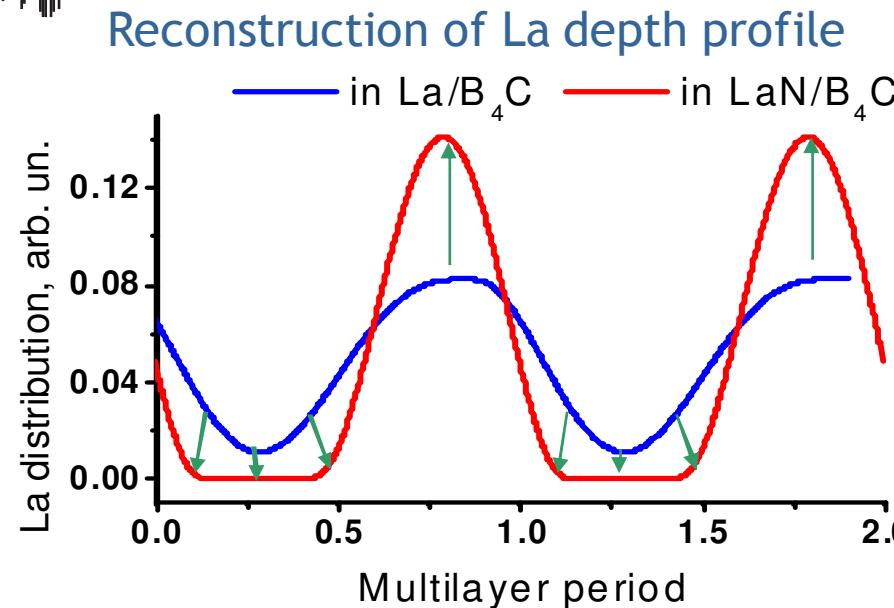
At interfaces: 7 La + 6 B₄C → 4 LaB₆ + 3 LaC₂ ($\Delta H = -305.4 \text{ kJ/mole}$)

Solution: nitride formation can prevent La-B and La-C compound formation

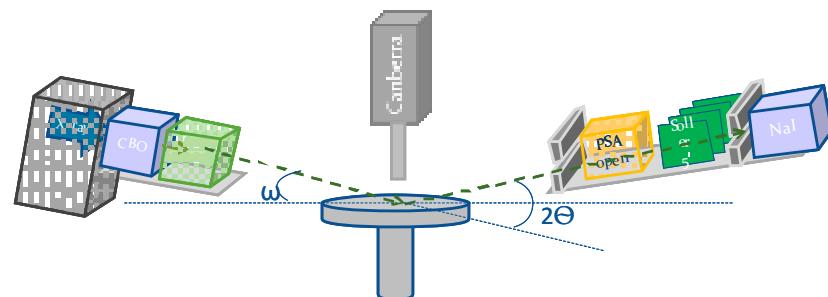
→ Introduce stable nitrides by N-ion treatment:
LaN can even enhance optical contrast ¹

¹T. Tsarfati, E. Louis, F. Bijkerk, et. all.,
Thin Solid Films 518, 24, 7249-7252 (2010)

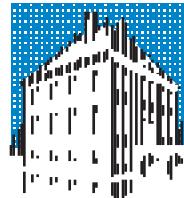
How does LaN perform in reflectance?



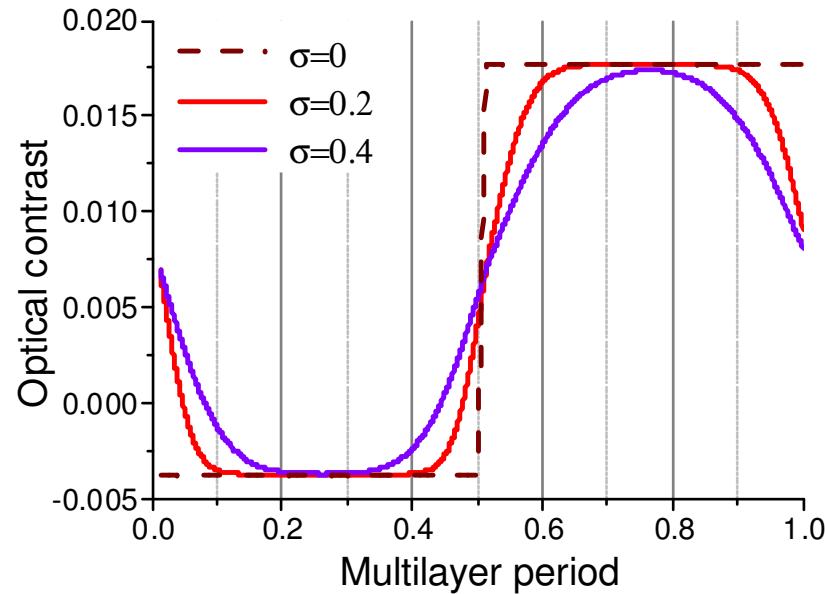
Dramatic difference in maximum reflectance
Without any process optimization
(Only 75 period multilayers)



Nitridation of La →
key to reducing layer
intermixing



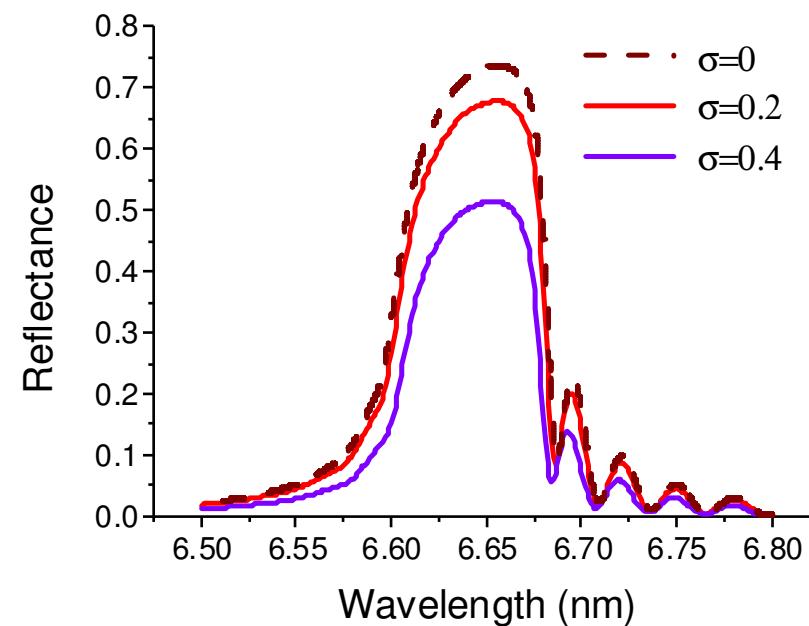
2nd challenge: roughness reduction



Calculations for 200 period LaN/B₄C multilayer:

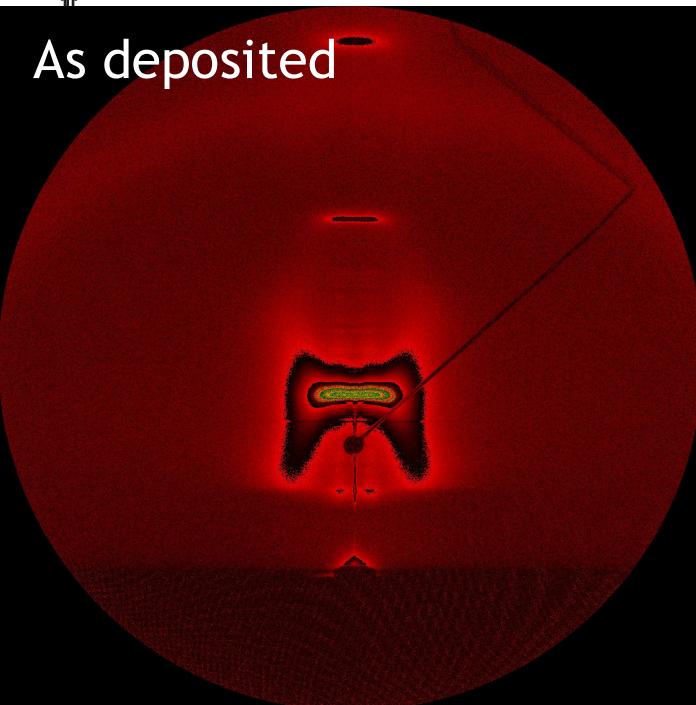
Roughness (σ) reduction from 0.4 to 0.2 nm
→ significant reflectivity gain

Roughness control is essential





Scattering from interfaces

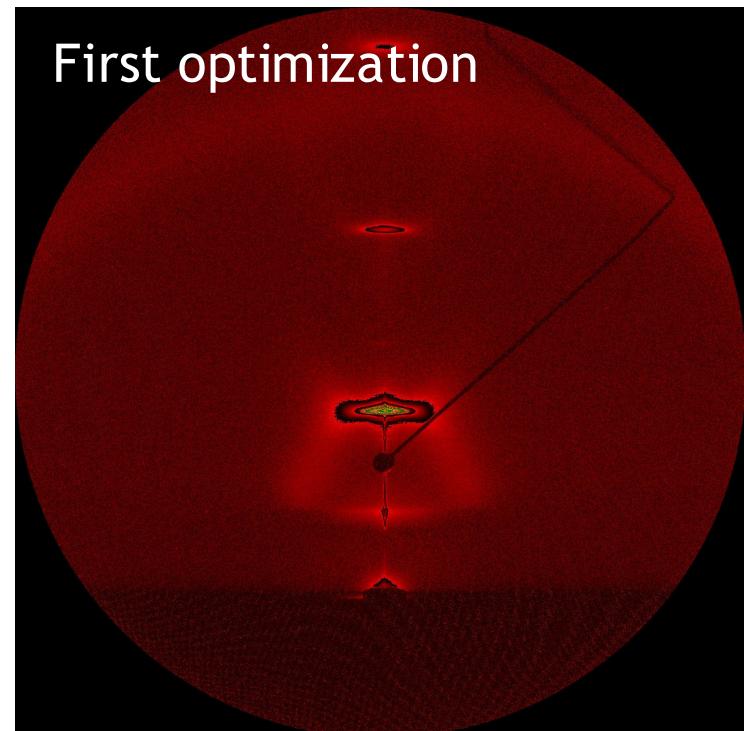


Growth optimization
→ Smoothing mechanisms
→ Kinetic growth manipulation

Process optimization →
smoother interfaces

→ Individual interface roughness: 0.3-0.6 nm

→ No severe increase roughness with number of layers

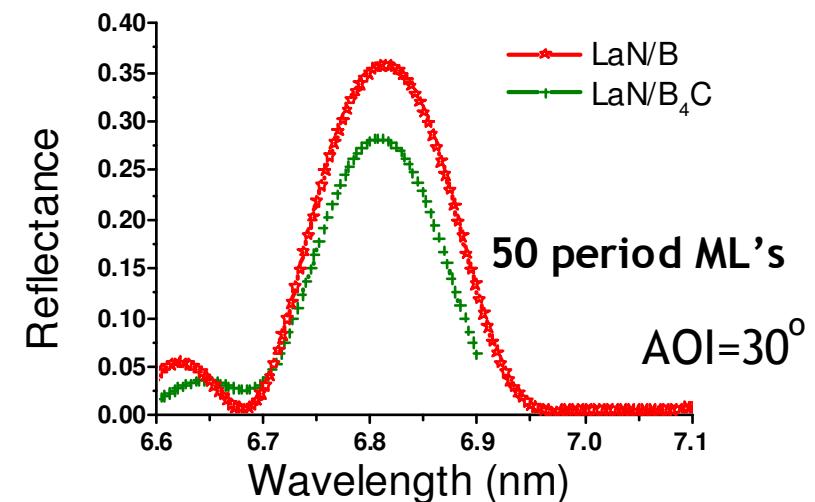
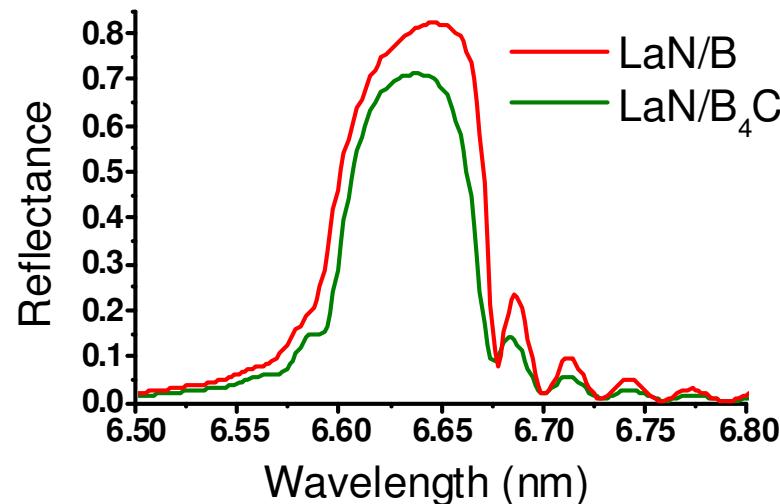




3rd challenge: optimal optical contrast

Replacement $B_4C \rightarrow B$: enhancement of the optical contrast

200 period ML's



Calculations on ideal multilayers
using measured^{1,2} optical constants:
→ 10% reflectivity gain

Measurements of pilot samples confirm
reflectivity gain
→ Deposition pure B to be optimized

Replacement of B₄C with B →
reflectivity gain expected

1. R. Soufli et. al., Appl. Opt., Vol. 47, 25, 2008
2. M. Fernandez-Perea et. al., J. Opt. Soc. Am. A, Vol. 24, 12, 2007



ASML

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GATE FOM



Outline

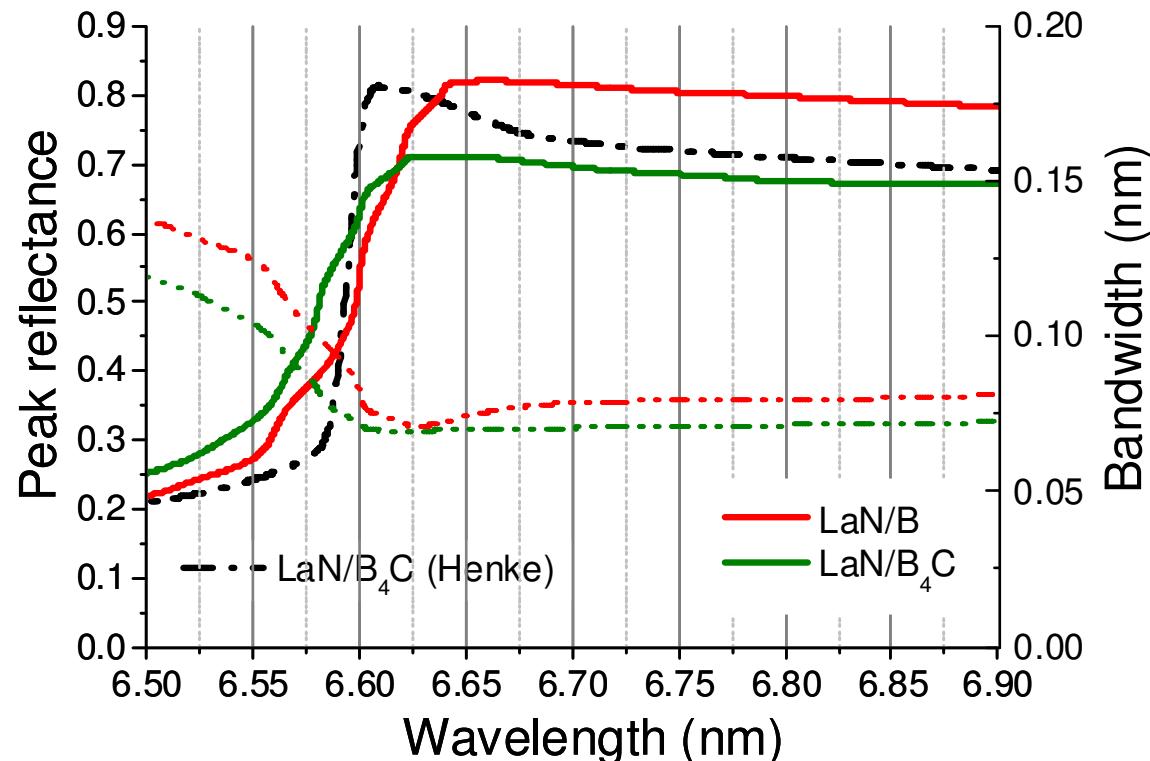
- FOM, who we are ...
 - 14 years of extensive 13.5 nm research
 - Coating research is essential key to new generation
- 6.x multilayer issues (a.o. materials) to determine performance and optimum operational wavelength
 - Passivation of La with Nitrogen
 - Roughness reduction
 - $B_4C \rightarrow B$
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Calculated multilayer reflectance

Optical constants:

- R. Soufli et. al., Appl. Opt., Vol. 47, 25, 2008
- M. Fernandez-Perea et. al., J. Opt. Soc. Am. A, Vol. 24, 12, 2007

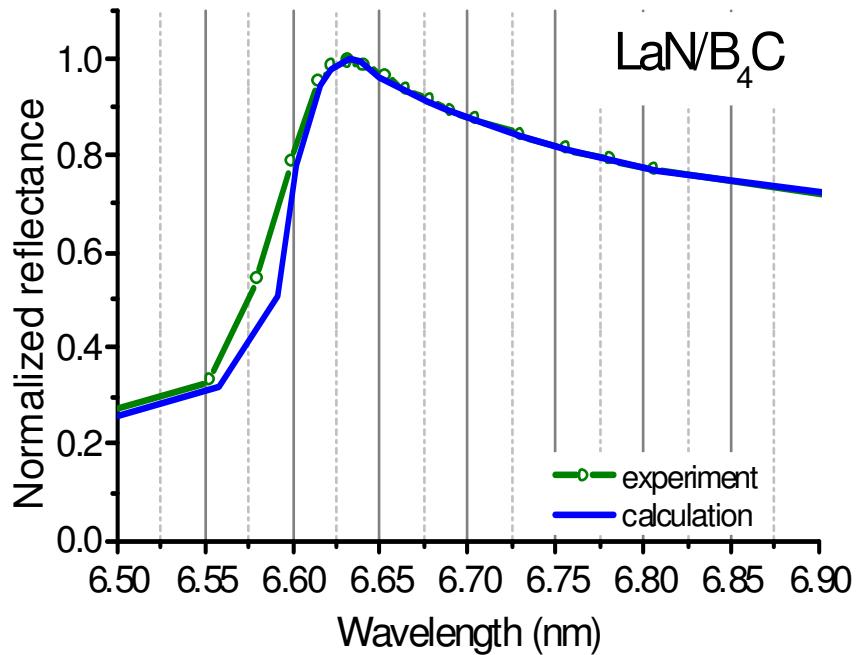
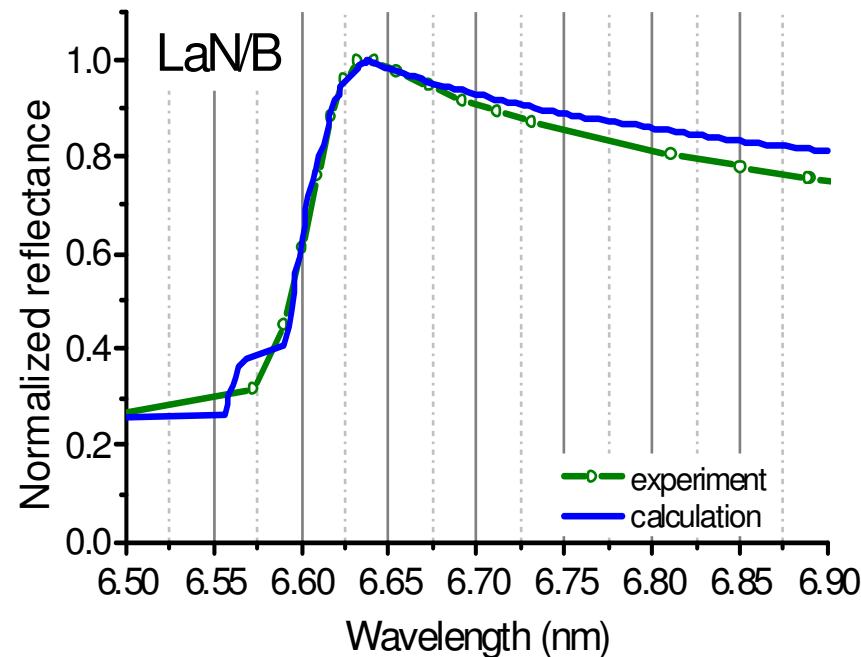


Perfect multilayer: → LaN/B: maximum reflectance at 6.66 nm
→ LaN/B₄C: maximum reflectance at 6.63 nm



Can optical constants be trusted?

$R(\lambda)$ measured at various angles of incidence



Calculated maximum confirmed by measured data →
optical constants reliably predicts optimal wavelength!



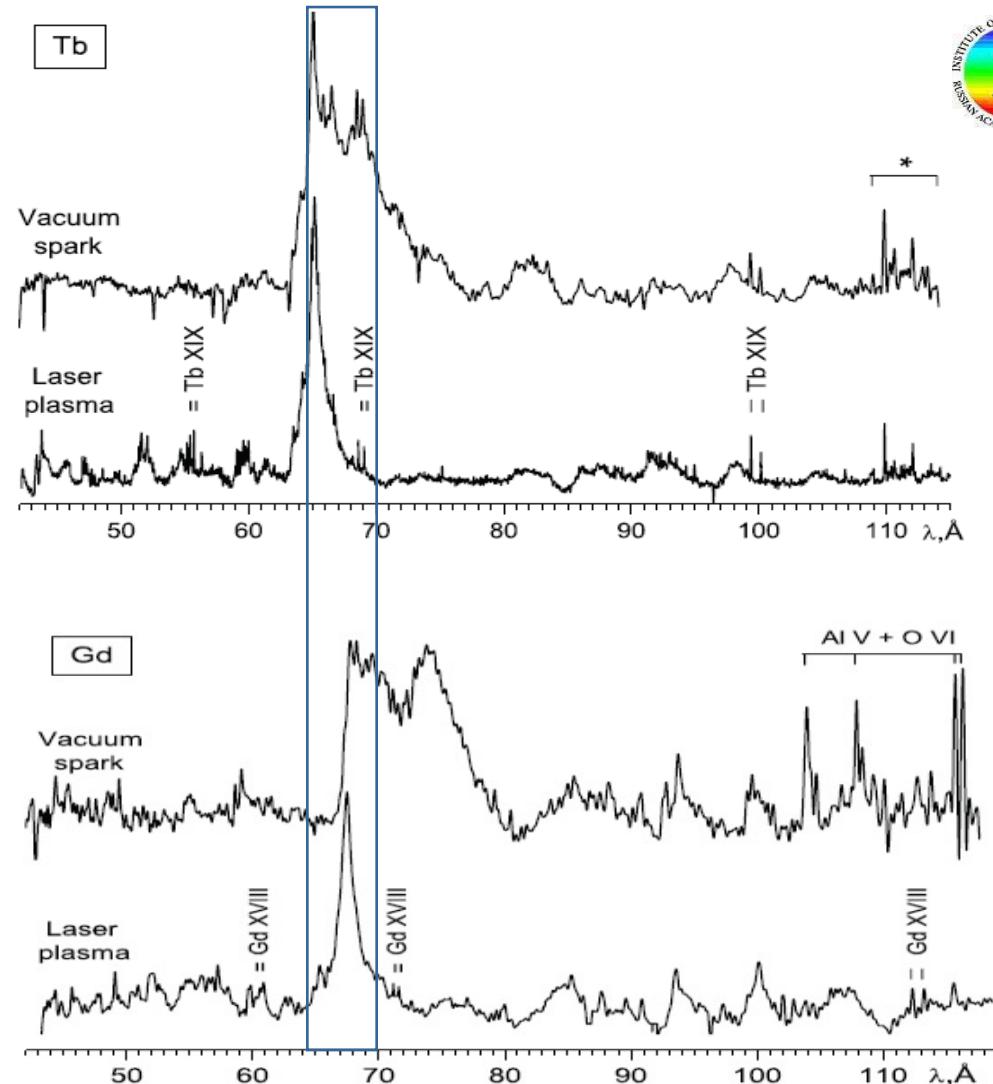
What about the source?

Determination wavelength
6.x nm lithography:

Simultaneous optimization
required:

- source
- multilayer performance
- optical design

*Candidate wavelength
band: 6.5-7.0 nm*

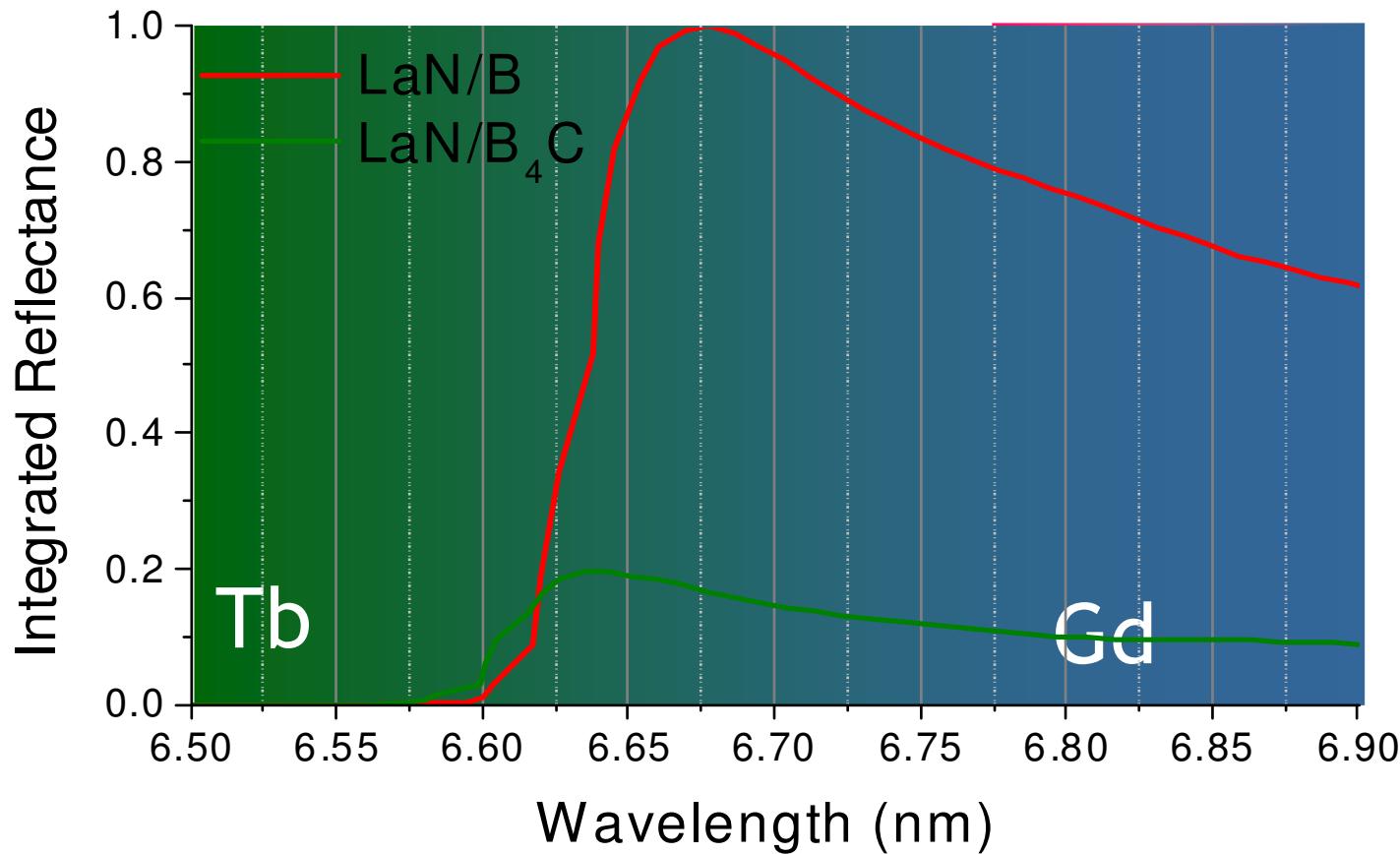


S.S. Churilov et al., Phys. Scr. 80 (2009)





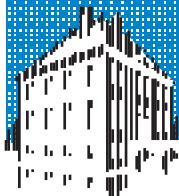
Throughput of a 10 mirror system



Significantly larger throughput for LaN/B based optics !

Optimal wavelength: LaN/B₄C: $\lambda=6.64$ nm; LaN/B: $\lambda=6.67$ nm

Based on 10 ML reflectivity: Tb $\lambda > 6.63$ nm; Gd $\lambda > 6.78$ nm



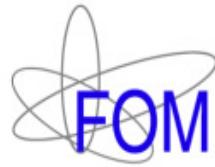
Conclusions

- La-B interdiffusion strongly suppressed by nitridation:
 $\text{La/B}_4\text{C} \rightarrow \text{LaN/B}_4\text{C}$
- $\text{LaN/B}_4\text{C} \rightarrow \text{LaN/B}$ enhanced reflectance
→ experimentally confirmed
- Preferred multilayer wavelength value: 6.63 nm or higher
- LaN/B 10 mirror system: highest throughput at 6.67 nm
- Source: Tb: $\lambda > 6.63$ nm
Gd: $\lambda > 6.78$ nm
→ Choice to be made also by source arguments



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and



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Hamburg and



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